DEVELOP NANOCOMPOSITE MATERIAL of TiO_2/Al_2O_3 USING ELECTROPHORETIC DEPOSITION

MONAF ALI RAHEM

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical-Materials Engineering)

Faculty Mechanical Engineering
Universiti Teknologi Malaysia

JULY 2014

This work is dedicated to my beloved ,

father , mother ,brothers and sisters

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Yob Saed B . Ismail , for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisors Professor Dr.. Noriah Bidin for their guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master's degree study. Librarians at UTM, special thanks for their assistance in supplying the relevant literatures.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

.

.

ABSTRACT

The methods have been developed for the manufacture of electrochemical deposition of coatings nanocomposite . Methods based on the electrophoretic deposition of nanoparticles . The method was developed for the deposition of EPD TiO_2 nanostructured films Al_2O_3 use of new agents to disperse . Copper has good corrosion resistance at room temperature , excellent malleability reproduction and susceptibility and electrical connections and high thermal , and apart from this it is cheap and abundantly available other metals from metals such as silver good measure . But poor mechanical properties such as hardness and wear resistance . Some applications , such as telecommunications switches require improvements in mechanical properties without losing a lot of heat and electrical connections . I have tried most of the modification alloying , but restrictions have been reported in alloying and reduce the negative in the thermal and electrical connections to it. Another way to improve the mechanical properties are modified with the surface through the development of composite coating on its surface .. has developed a coating with 10 g / l , and 30 g / l and 0 g / l concentrations that are not supported in the bath , in four different current densitie (5 A/dm^2) with the use of copper sulfate bath in order to study the effect of current density and the concentration of particles in the bath , on the structure and properties of advanced coating . The average crystal size in 64 -71 nm , and was obtained (220) strong texture in the paint and coatings copper compound is backed by identifying data XRD. Has been studied morphology and composition of the paint surface using SEM. Been determined hardness and wear resistance of coatings using micro- hardness testing and the ball on the plate wear test , and improve the hardness and wear resistance of the composite coatings were observed compared with copper paint is supported.

ABSTRAK

Kaedah-kaedah telah dibangunkan untuk pembuatan pemendapan elektrokimia penyalutan nan ocomposite. Kaedah melibatkan pemendapan elektroforetik nanopartikel. Kaedah ini telah dibangunkan untuk pemendapan EPD TiO_2 filem bernanostruktur penggunaan Al_2O_3 ejen baru untuk bersurai. Tembaga mempunyai ketahanan kakisan yang baik pada suhu bilik, pembiakan sifat lunak yang sangat baik dan kecenderungan dan sambungan elektrik dan haba yang tinggi, dan selain daripada ini adalah murah dan banyak terdapat logam lain daripada logam seperti perak langkah yang baik. Tetapi sifat-sifat mekanikal miskin seperti kekerasan dan rintangan haus. Sesetengah aplikasi, seperti suis telekomunikasi memerlukan peningkatan dalam sifat mekanik tanpa kehilangan banyak haba dan sambungan elektrik. Saya telah mencuba kebanyakan pengaloi pengubahsuaian, tetapi sekatan telah dilaporkan di pengaloian dan mengurangkan negatif dalam sambungan haba dan elektrik kepadanya. Satu lagi cara untuk meningkatkan sifat-sifat mekanikal diubah suai dengan permukaan melalui pembangunan salutan komposit di permukaannya .. telah membangunkan salutan dengan 10 g / l, dan 30 g / l dan 0 g / l kepekatan yang tidak disokong dalam mandi, dalam empat berbeza densitie semasa (5 A/dm^2) dengan menggunakan mandi tembaga sulfat untuk mengkaji kesan ketumpatan arus dan kepekatan zarah di dalam bilik mandi, kepada struktur dan sifat-sifat lapisan maju. Saiz kristal purata dalam 64 -71 nm, dan telah diperolehi (220) tekstur kukuh dalam cat dan salutan sebatian tembaga disokong dengan mengenal pasti XRD data. Telah dikaji morfologi dan komposisi permukaan cat menggunakan SEM. Telah ditentukan kekerasan dan rintangan haus salutan menggunakan ujian mikro kekerasan dan bola pada ujian plat memakai, dan meningkatkan kekerasan dan memakai rintangan salutan komposit diperhatikan berbanding dengan cat tembaga disokong.

TABLE OF CONTENTS

LAST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

The field of nanocomposite materials has attracted attention of of scientists and engineers in recent years. Nanomaterials have attracted more and more compound of interest for the purpose of creation , which is expected to provide many of the advanced features of high-performance or high- functional materials . And the Compositecarries very different characteristics of the original components . And therefore , can not be of material which was built to be a multi-functional (Zhitomirsky, 2006).

The Composite is one of the most important categories of engineered materials , they provide many of the distinct characteristics compared with conventional materials . I have found this material applications increasingly wider in the general areas of chemistry, and physics , nanotechnology and materials science

and engineering. Copper (Cu) is an environment -friendly materials and abundantly available , which has a unique combination of low electrical resistivity (16.78x10 $^{-9}$ Ωm) and high thermal conductivity (394 WM-1K -1), excellent malleability portability, attractive colors , reasonable resistance good corrosion at room temperature and recycling , and apart from this it is cheaper than other metals action (See, 1995).

Because of these characteristics of an excellent range of copper and its alloys are the most widely used and widely engineering materials for electrical conductivity (electrical connectors , wiring , connections , and plugs) and hea (heat exchangers, cushions, radiators , poles) . However , poor mechanical property often requires promote without adversely affecting the electrical conduction convection her . Some applications , such as electrical contacts require surface good mechanical properties such as hardness basis , and corrosion resistance due to work rubbing repeatedly during the switch . Bulk modification alloying reduces the thermal and electrical conductivity , and along with the electrical conductivity , and thermal conductivity is also important so that communication can be called quickly accumulated heat due to the resistance heating and rubbing action during the switch. In such an approach surface engineering components is one of the wise because it does not adversely affect the bulk properties such as thermal and electrical connections , compared with wholesale amendment . A wide variety of surface coating techniques available are physical vapor deposition , chemical vapor deposition , thermal spraying , electrophoresis, deposition of electricity , and the spread of the paint , and the techniques that rely laser (laser cladding , etc.) . nanocomposites and metal matrix containing dispersed particles of the second phase of our various special properties such as hardening of the dispersion , and self-lubricity , high temperature inertness , and good wear and corrosion resistance , and chemical and biological compatibility (Schnable, 1993).

Electrocodeposition has several advantages in the development of metal matrix composite coatings among other operations , such as deposits in the form of a unified complex substrates , and low cost , good reproducibility and reduce waste .

The Electrocodeposition process in use successfully for the development of such coatings nanocomposite of the past decades . Can be a hard second phase oxide (Al_2O_3, TiO_2) (Gul , 2009) .

These applications include coatings wear and corrosion resistant surfaces , lubrication , tools high hardness , alloy and enhance dispersion , and protection against oxidation and hot corrosion (Saha , 2010) .

To work in parallel operation panel electrical current is used to improve the surface mechanical properties of copper without causing a negative It wiring harnesses and heat , by placing a layer of coating nanocomposite consists of a matrix of copper nanoparticle (TiO_2 , Al_2O_3) on the copper surface . And determine the optimum current density and the concentration of particles in the bath with the results achieved coating (Boccaccini, 2002).

Quality deposits are affected by a large number of variables that include current density , and the properties of the particles , and the formation of a bath, hydrodynamics and particle interaction bath . The amount of particles is an integral part of the second phase plays an important role in improving the mechanical properties of the surface by adjusting the grain size of the matrix , and also enhance the dispersion mechanism . Many of the parameters affecting the folder included . % Of second phase particles , including current density , and the particle concentration in the bath , and the pH of the solution are important variables . Current density plays an important role in the control of the deposition rate , which will in turn affect the concentration of particles included in the paint (Thiemig, 2008).

1.2 Objectives Of The Study

1. To synthesize nanocomposite TiO_2 and Al_2O_3 on copper substrate using electrophoretic deposition technique.

2. Investigation of deposition mechanism, and kinetics of deposition.

3. To determine the optimum concentration of composite TiO_2/ Al_2O_3 on copper substrate.

4. To determine the characterizations of the coating substrate

1.3 Scope of the Work

Organizing the rest of the letter is as follows: for the preparation of nanocomposite TiO_2 / Al_2O_3 using the method of deposition Electrophoric. Mechanisms to promote different from copper , a brief explanation of the process of electrolysis with advantages over other coating techniques and applications and about codeposition electric , the impact of various factors on the characteristics of electrical codeposited coatings , and their applications , and review of the literature and a brief on the copper , and TiO_2 , Al_2O_3 provided paint compound in Chapter 2 . An experimental study has provided a detailed and different techniques on the descriptions in Chapter 3 . In Chapter 4, a discussion on the results that have been obtained from the descriptions of the powders (TiO_2 , Al_2O_3) along with the study of the mechanical property and provided samples of different co- deposited . In

Chapter 5 has been reported summary results and the main conclusions of this work . The references provided in Chapter 6 .

REFERENCES

Abdel Aal, A., & Hassan, H. B. (2009). Electrodeposited nanocomposite coatings for fuel cell application. *Journal of Alloys and Compounds*, *477*(1), 652-656.

Akarapu, A. (2011). *Surface Property Modification of Copper by Nanocomposite Coating* (Doctoral dissertation).

Aruna, S. T., William Grips, V. K., & Rajam, K. S. (2009). Ni-based electrodeposited composite coating exhibiting improved microhardness, corrosion and wear resistance properties. *Journal of Alloys and compounds*,*468*(1), 546-552.

Baer, D. R., Burrows, P. E., & El-Azab, A. A. (2003). Enhancing coating functionality using nanoscience and nanotechnology. *Progress in Organic Coatings*, *47*(3), 342-356.

Balaraju, J. N., Narayanan, T. S., & Seshadri, S. K. (2003). Electroless Ni–P composite coatings. *Journal of applied electrochemistry*, *33*(9), 807-816.

Basu, R. N., Randall, C. A., & Mayo, M. J. (2001). Fabrication of dense zirconia electrolyte films for tubular solid oxide fuel cells by electrophoretic deposition.*Journal of the American Ceramic Society*, *84*(1), 33-40.

Besra, L., & Liu, M. (2007). A review on fundamentals and applications of electrophoretic deposition (EPD). *Progress in materials science*, *52*(1), 1-61.

Besra, L., Compson, C., & Liu, M. (2006). Electrophoretic Deposition of YSZ Particles on Non-Conducting Porous NiO–YSZ Substrates for Solid Oxide Fuel Cell Applications. *Journal of the American Ceramic Society*, *89*(10), 3003-3009.

Boccaccini, A. R., & Zhitomirsky, I. (2002). Application of electrophoretic and electrolytic deposition techniques in ceramics processing. *Current Opinion in Solid State and Materials Science*, *6*(3), 251-260.

Bohmer, M. (1996). In situ observation of 2-dimensional clustering during electrophoretic deposition. *Langmuir*, *12*(24), 5747-5750.

Boonyongmaneerat, Y., Saengkiettiyut, K., Saenapitak, S., & Sangsuk, S. (2009). Effects of WC addition on structure and hardness of electrodeposited Ni–W. *Surface and Coatings Technology*, *203*(23), 3590-3594.

Cao, G. (2004). *Synthesis, properties and applications*. Imperial College Press: London.

Chattopadhyay, R. (2004). *Advanced thermally assisted surface engineering processes*. Springer.

Chawla, V., Jayaganthan, R., & Chandra, R. (2009). Microstructural characteristics and mechanical properties of magnetron sputtered nanocrystalline TiN films on glass substrate. *Bulletin of Materials Science*,*32*(2), 117-123.

Chen, W. L., Huang, C. Y., & Hung, C. W. (2010). Optimization of plastic injection molding process by dual response surface method with non-linear programming. *Engineering computations*, *27*(8), 951-966.

Chu, X. L., Nikolov, A. D., & Wasan, D. T. (1995). Thin liquid film structure and stability: The role of depletion and surface-induced structural forces. *The Journal of chemical physics*, *103*(15), 6653-6661.

Corni, I., Ryan, M. P., & Boccaccini, A. R. (2008). Electrophoretic deposition: from traditional ceramics to nanotechnology. *Journal of the European Ceramic Society*, *28*(7), 1353-1367.

Corni, I., Ryan, M. P., & Boccaccini, A. R. (2008). Electrophoretic deposition: from traditional ceramics to nanotechnology. *Journal of the European Ceramic Society*, *28*(7), 1353-1367.

Craig, B. D. (2005). Material failure modes, part II: A brief tutorial on impact, spalling, wear, brinelling, thermal shock, and radiation damage. *Journal of Failure Analysis and Prevention*, *5*(6), 7-12.

Dalla Corte, D. A., Torres, C., Correa, P. D. S., Rieder, E. S., & Malfatti, C. D. F. (2012). The hydrogen evolution reaction on nickel-polyaniline composite electrodes. *International Journal of Hydrogen Energy*, *37*(4), 3025-3032.

Damodaran, R., & Moudgil, B. M. (1993). Electrophoretic deposition of calcium phosphates from non-aqueous media. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *80*(2), 191-195.

Dittmer, M. P., Kohorst, P., Borchers, L., & Stiesch-Scholz, M. (2009). Finite element analysis of a four-unit all-ceramic fixed partial denture. *Acta biomaterialia*, *5*(4), 1349-1355.

Fan, G., Sun, F., Meng, X., Gao, L., & Tong, G. (2010). Electric hot incremental forming of Ti-6Al-4V titanium sheet. *The International Journal of Advanced Manufacturing Technology*, *49*(9-12), 941-947.

Ferrari, B., & Moreno, R. (2010). EPD kinetics: a review. *Journal of the European Ceramic Society*, *30*(5), 1069-1078.

Gao, J., Gu, H., & Xu, B. (2009). Multifunctional magnetic nanoparticles: design, synthesis, and biomedical applications. *Accounts of chemical research*, *42*(8), 1097-1107.

Gul, H., Kılıç, F., Aslan, S., Alp, A., & Akbulut, H. (2009). Characteristics of electro-co-deposited Ni–Al< sub> 2</sub> O< sub> 3</sub> nano-particle reinforced metal matrix composite (MMC) coatings. *Wear*, *267*(5), 976-990.

Guo, D., Zhang, M., Jin, Z., & Kang, R. (2007). Effect of direct current and pulse plating on the EDM performance of copper-zirconium diboride composites.*Journal of University of Science and Technology Beijing, Mineral, Metallurgy, Material*, *14*(5), 464-468.

Gurrappa, I., & Binder, L. (2008). Electrodeposition of nanostructured coatings and their characterization—a review. *Science and Technology of Advanced Materials*, *9*(4), 043001.

Harbach, F., & Nienburg, H. (1998). Homogeneous functional ceramic components through electrophoretic deposition from stable colloidal suspensions—II. Beta-alumina and concepts for industrial production. *Journal of the European Ceramic Society*, *18*(6), 685-692.

Hasegawa, K., Kunugi, S., Tatsumisago, M., & Minami, T. (1999). Preparation of thick films by electrophoretic deposition using surface modified silica particles derived from sol-gel method. *Journal of sol-gel science and technology*, *15*(3), 243-249.

Hirose, A., & Kobayashi, K. F. (1994). Surface alloying of copper with chromium by CO< sub> 2</sub> laser. *Materials Science and Engineering: A*,*174*(2), 199-206.

Hitchman, M. L., & Jensen, K. F. (Eds.). (1993). *Chemical Vapor Deposition: Principles and Applications* (Vol. 21). London: Academic Press.

Hou, K. H., Ger, M. D., Wang, L. M., & Ke, S. T. (2002). The wear behaviour of electro-codeposited Ni–SiC composites. *Wear*, *253*(9), 994-1003.

Jiang, N., Meng, H. M., Song, L. J., & Yu, H. Y. (2010). Study on Ni–Fe–C cathode for hydrogen evolution from seawater electrolysis. *International Journal of Hydrogen Energy*, *35*(15), 8056-8062.

Kamada, K., Mukai, M., & Matsumoto, Y. (2003). Electrophoretic deposition assisted by soluble anode. *Materials Letters*, *57*(16), 2348-2351.

Kanamura, K., & Hamagami, J. I. (2004). Innovation of novel functional material processing technique by using electrophoretic deposition process. *Solid State Ionics*, *172*(1), 303-308.

Kataoka, S., Gurau, M. C., Albertorio, F., Holden, M. A., Lim, S. M., Yang, R. D., & Cremer, P. S. (2004). Investigation of water structure at the TiO2/aqueous interface. *Langmuir*, *20*(5), 1662-1666.

Kennedy, D., Xue, Y., & Mihaylova, E. (2005). Current and future applications of surface engineering.

Koch, C. C. (2009, January). Processing-structure-property relationships in ultrafine grain and nanocrystalline materials. In *Journal of Physics: Conference Series* (Vol. 144, No. 1, p. 012081). IOP Publishing.

Kralchevsky, P. A., & Nagayama, K. (1994). Capillary forces between colloidal particles. *Langmuir*, *10*(1), 23-36.

Labib, M. E., & Williams, R. (1984). The use of zeta-potential measurements in organic solvents to determine the donor—acceptor properties of solid surfaces.*Journal of colloid and interface science*, *97*(2), 356-366.

Lajevardi, S. A., & Shahrabi, T. (2010). Effects of pulse electrodeposition parameters on the properties of Ni–TiO< sub> 2</sub> nanocomposite coatings. *Applied Surface Science*, *256*(22), 6775-6781.

Last, W. M. (2001). Mineralogical analysis of lake sediments. In *Tracking environmental change using lake sediments* (pp. 143-187). Springer Netherlands.

Lee, H. K., Lee, H. Y., & Jeon, J. M. (2007). Codeposition of micro-and nano-sized SiC particles in the nickel matrix composite coatings obtained by electroplating. *Surface and Coatings Technology*, *201*(8), 4711-4717.

Leonard, B., Sadeghi, F., & Cipra, R. (2008). Gaseous cavitation and wear in lubricated fretting contacts. *Tribology Transactions*, *51*(3), 351-360.

Lerner, R. N., Lu, Q., Zeng, H., & Liu, Y. (2012). The effects of biofilm on the transport of stabilized zerovalent iron nanoparticles in saturated porous media.*Water research*, *46*(4), 975-985.

Low, C. T. J., Wills, R. G. A., & Walsh, F. C. (2006). Electrodeposition of composite coatings containing nanoparticles in a metal deposit. *Surface and Coatings Technology*, *201*(1), 371-383.

Lu, X., Zhu, R., & He, Y. (1995). Electrophoretic deposition of MCrAlY overlay-type coatings. *Oxidation of metals*, *43*(3-4), 353-362.

Merchant, H. D., Liu, W. C., Giannuzzi, L. A., & Morris, J. G. (2004). Grain structure of thin electrodeposited and rolled copper foils. *Materials characterization*, *53*(5), 335-360.

Morshed, A. K. M. M., Paul, T. C., & Khan, J. (2013). Effect of Cu – Al2O3 nanocomposite coating on flow boiling performance of a microchannel. *Applied Thermal Engineering*, *51*(1), 1135-1143.

Osborne, S. J., Sweet, W. S., Vecchio, K. S., & Talbot, J. B. (2007). Electroplating of Copper–Alumina Nanocomposite Films with an Impinging Jet Electrode. *Journal of The Electrochemical Society*, *154*(8), D394-D399.

Pang, X., & Zhitomirsky, I. (2005). Electrodeposition of nanocomposite organic–inorganic coatings for biomedical applications. *International Journal of Nanoscience*, *4*(03), 409-418.

Pant, H. R., Bajgai, M. P., Nam, K. T., Seo, Y. A., Pandeya, D. R., Hong, S. T., & Kim, H. Y. (2011). Electrospun nylon-6 spider-net like nanofiber mat containing TiO< sub> 2</sub> nanoparticles: a multifunctional nanocomposite textile material. *Journal of hazardous materials*, *185*(1), 124-130.

Pellicer, E., Varea, A., Sivaraman, K. M., Pané, S., Surinach, S., Baró, M. D. & Sort, J. (2011). Grain Boundary Segregation and Interdiffusion Effects in Nickel–Copper Alloys: An Effective Means to Improve the Thermal Stability of Nanocrystalline Nickel. *ACS applied materials & interfaces*, *3*(7), 2265-2274.

Pierson, H. O. (1999). *Handbook of chemical vapor deposition: principles, technology and applications*. William Andrew.

Quale, S. L., & Talbot, J. B. (2007). Electrophoretic deposition of substrate-normal-oriented single-walled carbon nanotube structures. *Journal of The Electrochemical Society*, *154*(8), K25-K28.

Raj, C. J., Prabakar, K., Karthick, S. N., Hemalatha, K. V., Son, M. K., & Kim, H. J. (2013). Banyan Root Structured Mg-Doped ZnO Photoanode Dye-Sensitized Solar Cells. *The Journal of Physical Chemistry C*, *117*(6), 2600-2607.

Roos, J. R., Celis, J. P., & Kelchtermans, H. (1978). Dispersion-hardened electrolytic copper-alumina coatings. *Thin Solid Films*, *54*(2), 173-182.

Ryan, J. N., & Elimelech, M. (1996). Colloid mobilization and transport in groundwater. *Colloids and surfaces A: Physicochemical and engineering aspects*, *107*, 1-56.

Sader, J. E., & Chan, D. Y. (1999). Electrical double-layer interaction between charged particles near surfaces and in confined geometries. *Journal of colloid and interface science*, *218*(2), 423-432.

Saha, R. K., & Khan, T. I. (2010). Effect of applied current on the electrodeposited Ni–Al_2O_3 composite coatings .*Surface and Coatings Technology*, *205*(3), 890-895.

Saliba-Silva, A. M., Garcia, R. H. L., Martins, I. C., de Carvalho, E. F. U., & Durazzo, M. (2011). Uranium Briquettes for Irradiation Targets. In *2011 International Nuclear Atlantic Conference-(INAC)*.

Sarkar, P., & Nicholson, P. S. (1996). Electrophoretic deposition (EPD): mechanisms, kinetics, and application to ceramics. *Journal of the American Ceramic Society*, *79*(8), 1987-2002.

Sarkar, P., & Nicholson, P. S. (1996). Electrophoretic deposition (EPD): mechanisms, kinetics, and application to ceramics. *Journal of the American Ceramic Society*, *79*(8), 1987-2002.

Schnable, G. L. (1993). Manufacturing Defect Classification System. In*Microelectronics Manufacturing Diagnostics Handbook* (pp. 62-94). Springer US.

Schwartz, M. (1994). Deposition from aqueous solutions: an overview.*Handbook of Deposition Technologies for Films and Coatings—Science, Technology and Applications, William Andrew Publishing, Noyes*, 506.

Schwarzacher, W. (2006). Electrodeposition: a technology for the future.*Interface*, *15*(1), 32-35.

Seah, K. H. W., Sharma, S. C., & Girish, B. M. (1995). Mechanical properties of cast ZA-27/graphite particulate composites. *Materials & Design*, *16*(5), 271-275.

Shanthi, C., Barathan, S., Jaiswal, R., Arunachalam, R. M., & Mohan, S. (2008). The effect of pulse parameters in electro deposition of silver alloy.*Materials Letters*, *62*(30), 4519-4521.

Singh, B. P., Menchavez, R., Takai, C., Fuji, M., & Takahashi, M. (2005). Stability of dispersions of colloidal alumina particles in aqueous suspensions.*Journal of colloid and interface science*, *291*(1), 181-186.

Sorkhe, Y. A., Aghajani, H., & Taghizadeh Tabrizi, A. (2014). Mechanical alloying and sintering of nanostructured TiO< sub> 2</sub> reinforced copper composite and its characterization. *Materials & Design*.

Sorkhe, Y. A., Aghajani, H., & Taghizadeh Tabrizi, A. (2014). Mechanical alloying and sintering of nanostructured TiO< sub> 2</sub> reinforced copper composite and its characterization. *Materials & Design*.

Sriraman, K. R., Ganesh Sundara Raman, S., & Seshadri, S. K. (2006). Synthesis and evaluation of hardness and sliding wear resistance of electrodeposited nanocrystalline Ni–W alloys. *Materials Science and Engineering: A*, *418*(1), 303-311.

Sriraman, K. R., Ganesh Sundara Raman, S., & Seshadri, S. K. (2006). Synthesis and evaluation of hardness and sliding wear resistance of electrodeposited nanocrystalline Ni–W alloys. *Materials Science and Engineering: A*, *418*(1), 303-311.

Sun, F., Pang, X., & Zhitomirsky, I. (2009). Electrophoretic deposition of composite hydroxyapatite–chitosan–heparin coatings. *Journal of materials processing technology*, *209*(3), 1597-1606.

Sun, Y. (2012). ELECTROPHORETIC DEPOSITION OF ORGANIC-INORGANIC NANOCOMPOSITES.

Thiemig, D., & Bund, A. (2008). Characterization of electrodeposited Ni–TiO_2 nanocomposite coatings. *Surface and Coatings Technology*,*202*(13), 2976-2984.

Thiemig, D., Lange, R., & Bund, A. (2007). Influence of pulse plating parameters on the electrocodeposition of matrix metal nanocomposites. *Electrochimica Acta*, *52*(25), 7362-7371.

Trau, M., Saville, D. A., & Aksay, I. A. (1997). Assembly of colloidal crystals at electrode interfaces. *Langmuir*, *13*(24), 6375-6381.

Vakhrushev, A. V., & Molchanov, E. K. (2012). MODELING ELECTROCHEMICAL DEPOSITION OF AI< sub> 2</sub> O< sub> 3</sub> NANOPARTICLES INTO A Cu MATRIX. *Nanomechanics Science and Technology: An International Journal*, *3*(4).

Van der Biest, O. O., & Vandeperre, L. J. (1999). Electrophoretic deposition of materials. *Annual Review of Materials Science*, *29*(1), 327-352.

Van der Biest, O. O., & Vandeperre, L. J. (1999). Electrophoretic deposition of materials. *Annual Review of Materials Science*, *29*(1), 327-352.

Van Tassel, J. J., & Randall, C. A. (2006). Mechanisms of electrophoretic deposition. *Key Engineering Materials*, *314*, 167-174.

Wang, J., Iwahashi, Y., Horita, Z., Furukawa, M., Nemoto, M., Valiev, R. Z., & Langdon, T. G. (1996). An investigation of microstructural stability in an Al□ Mg alloy with submicrometer grain size. *Acta materialia*, *44*(7), 2973-2982.

Zamblau, I., Varvara, S., Bulea, C., & Muresan, L. M. (2009). Corrosion Behavior of Composite Coatings Obtained by Electrolytic Codeposition of Copper with Al2O3 Nanoparticles. *Chemical and Biochemical Engineering Quarterly*, *23*(1), 43-52.

Zhang, H., Jiang, Z., & Qiang, Y. (2009). Microstructure and tensile deformation of nanocrystalline Cu produced by pulse electrodeposition. *Materials Science and Engineering: A*, *517*(1), 316-320.

Zhitomirsky, I. (1998). Cathodic electrophoretic deposition of diamond particles.*Materials Letters*, *37*(1), 72-78.

Zhitomirsky, I. (2006). Electrophoretic deposition of organic–inorganic nanocomposites. *Journal of materials science*, *41*(24), 8186-8195.

Zhu, J., Liu, L., Hu, G., Shen, B., Hu, W., & Ding, W. (2004). Study on composite electroforming of Cu / SiC pcomposites. *Materials Letters*, *58*(10), 1634-1637.